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## Contents



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# MAGNETIC STORM AND ELECTRIC POWER LINE DISTURBANCE CYCLES

BY DAVID WILLIAMS

## Overhead Electric Power System Disturbances

While communication engineers have long been aware of the effects of solar disturbances, power engineers generally did not realize that magnetic storms could reach such magnitudes as to cause operating disturbances in electric power systems, until the great magnetic storm of March 24, 1940. Davidson[1,2] reported that on the Consolidated Edison 60 cycle system in New York, voltage dips varied from 1 1/2 to 10 per cent in different parts of the system, whereas the 25 cycle system voltage was not affected, nor was there any appreciable change in system frequency or in KW load in any part of either system. He summarized the disturbances on ten power systems located in New England, New York, eastern Pennsylvania, southern and eastern Minnesota, Ontario and Quebec, as follows:

(a) 7 cases of voltage dips ranging up to 10%, but generally of short duration.
(b) 5 cases (15 transformer banks) of transformer tripping by differential relay operation.
(c) 4 cases of large increases or swings in reactive kilovolt-amperes.
(d) 1 case where direct current was measured in a neutral grounding.
(e) 1 case of distortion of the current wave in a neutral grounding.
(f) 1 case of a few blown transformer fuses on a 2400/4150 volt radial distribution system.

Germaine[3] reported that the storm interrupted nearly all overseas, radiotelephone circuits, service to ships at sea, and a number of long distance land telephone and other communication services, such as the telephotograph network and major network broadcasting facilities. It was believed that voltages in excess of 500 were experienced between certain stations, making it necessary to replace nearly 800 protector blocks in the state of Wisconsin alone.

On November 11, 1960, the North Atlantic Radio Warning Service of the National Bureau of Standards issued a "Special Disturbance Warning" predicting disturbed radio propagation conditions on November 12-13. This warning was based on an *"importance three flare"* associated with a severe short wave fade-out and a major solar radio noise event on November 10. A geomagnetic disturbance followed this flare by slightly more than two days. After several hours of relatively low activity the storm became very severe and *proved to be the most severe ever to be observed by NARWS.* An unusually brilliant auroral display and disturbances to radio communications, which were widely noted in the press, accompanied this storm.

The System Operator of the Consolidated Edison Company of New York reported that,

"during several hours on Sunday, November 13, there were random occurrences of uncontrolled voltage variations of considerable magnitude in the voltage of the 138KV transmission system. Similar effects were reported by the System Operators of neighboring utility companies and also by the Hydro-Electric Power Commission of Ontario, Canada. It is believed that the disturbance was caused by higher than normal magnitude electric currents in the earth's surface, accompanying the present giant sunspot activity."

The mechanism thru which a solar disturbance affects large electric power systems is as follows: Changes in the earth's magnetism, probably caused by the ejection of charged particles from the disturbed portion of the sun, cause differences in earth potentials. Differences of earth potential at widely separated points, where wye-connected transformers in the transmission system have their neutrals grounded, are believed to cause direct currents to flow in such a manner as to partially saturate the transformer cores. The excitation requirements of the transformers are thereby increased and the system voltage drops in an erratic pattern.

McNish[4] concluded that the 1940 storm was even greater than that of April 1938, when energy was expended at the rate of two billion kilowatts for a two-hour interval. He stated that, Mathematical analysis has shown that field-changes during magnetic storms are due principally to causes above the earth's surface, presumably electric currents, and that these external effects are accompanied by effects due to the induction of currents within the earth by the primary external fields. The field changes may be divided into two classes—those which are symmetric about the earth's magnetic axis and those which are nonsymmetric. The first class may be thought of as due mainly to a large ring-current about the earth, like the rings of Saturn, or to a current flowing in the outer atmosphere with intensity varying as the cosine of the geomagnetic latitude from zero at the geomagnetic poles to a maximum at the equator."

But it wasn't until 1949 that experimental proof of the existence of this overhead current system was obtained by Singer, Maple, and Bowen[5] by means of magnetometers sent aloft in Aerobee rockets from a point in the Pacific Ocean near the equator. The results clearly established the presence of overhead currents of the order of 50,000 amperes in a layer between 93 and 105 KM above the earth.

Other ring currents as high as 1,000,000 amperes were found some 25,000 miles out in space, between 65 and 68 degrees North and South Geomagnetic latitude, by the U. S. Pioneer I satellite which soared nearly 80,000 miles on October 11, 1958, and Explorer VI which soared about 35,000 miles on August 7, 1959. Hence, Sonnet[6] believes that fluctuating magnetism in outer space may be responsible for the earth's auroral phenomena.

A ring current of 5,000,000 amperes 12,000 miles thick, was reported by Sonnet[7] as having been obtained from data telemetered by the U. S. Pioneer V satellite when it was about 3,000,000 miles from the earth. This ring lies at an altitude of 40,000 to 60,000 miles, well beyond the outer Van Allen belt, and flows westward around the earth, subtracting from the intensity of the earth's magnetic field on its inner side and adding to it on the outer edge. Sonnet and his associates also found that the sharp start of a magnetic storm on earth—known as a "sudden commencement"—had also been observed 3,000,000 miles out in space.

Where do the electromotive forces necessary to maintain such enormous currents originate? McNish[4] in 1940 concluded, "The cause of the primary electric currents in the outer atmosphere or about the earth remains a matter of speculation." He suggested, however, that the "ring-current" was a simple manifestation of the motion of the clouds of electrified corpuscles ejected by the sun, which upon striking the earth's upper atmosphere are focused by the earth's magnetic field, very much as electrons are focused by the magnetic field in the newly developed electron-microscope. This was based on mathematical analysis which showed that electrified particles of certain energies and masses would reach the atmosphere with greatest density in belts near the magnetic poles (auroral zones) and that others would occupy semi-stable orbits in the plane of the magnetic equator. This was experimentally demonstrated by Birkeland[8] in 1896, and seems to be confirmed by the data obtained from both Pioneer V and Explorer VI.

McNish[4] also suggested that the auroral-zone currents, which may exceed 1,000,000 amperes, with changes exceeding 100,000 amperes per minute, resulted from the convective motion of the atmosphere in the earth's magnetic field, by which means the currents are induced in accordance with the principles of the dynamo. This theory, (the atmospheric dynamo theory), was first advanced by Professor Balfour Stewart in 1882, and was mathematically developed by Sir Arthur Schuster in 1888 and 1907, and reconfirmed by Professor Sidney Chapman in 1913, 1919, and 1936.

Because data telemetered by Pioneer V from a distance of 3,000,000 miles showed variations in magnetic activity similar to those recorded at the same time in Hawaii and Virginia, Laurence[9] concluded, "Pioneer V informs us that these magnetic storms are not local

phenomena peculiar to our earth, but are rather due to some as yet unknown forces existing in space, possibly throughout the Milky Way Galaxy."

McNish[4] stated that, "Judging the future by the past, great magnetic storms may be expected at the rate of one a decade. Our records go further than this. They show that, including magnetic storms of all intensities, their frequency follows the 11-year sunspot cycle, lagging behind it by about two years." However, 20 years were to elapse before the Consolidated Edison system would experience a disturbance as severe as that of 1940. Since both disturbances occurred when the polarity of the sunspots was the same, i.e., North Spots Leading in the Northern Hemisphere of the Sun, (see Chart 1), it would indicate that electric power system disturbances might follow the 22-year sunspot cycle (alternate 11 year cycles reversed) instead of the usual 11-year cycle.

## Underground Cable Failures

The effect of magnetic storms on underground electric cables had been given little or no consideration until August 17, 1959, when failures on seven out of twenty 13.8KV cables serving the Central Park Network Area of the Consolidated Edison system necessitated the interruption of electric service to some 500,000 people. A severe magnetic storm, which blacked out radio communications, was raging at the time. An investigation was started to determine whether this was an isolated case or whether similar occurrences in the past were related.

Data for each of the six years 1955—1960 were obtained and charted as per Chart 2, which is for the year 1959. The Zurich Relative Sunspot Numbers are those of Dr. M. Waldmeier, Director of Zurich Observatory, from observations there and at its stations in Locarno and Arosa, Switzerland, as published in *"Sky and Telescope."* The A-Index of Geomagnetic Activity was developed for use during the International Geophysical Year, and the data, taken from the Fredericksburg Magnetic Observatory records of the U. S. Bureau of Standards, is stated to be much more precise than that measured by the visually indicating magnetographs in use at the Bureau's Ft. Belvoir, Va. station, which reports the K-Indices of Geomagnetic Activity.

The K-Index of Geomagnetic Activity is the sum of the positive and negative variations from normal intensity of the most disturbed of the magnetic field's three components, viz: (H) the Horizontal component, (V) the Vertical component, and (D) the angle between the direction of (H) and the magnetic meridian, which is known as the Magnetic Declination. Readings are taken at 3-hour intervals and plotted on a quasi-logarithmic scale 0 (very quiet) to 9 (extremely disturbed). The data recorded on Chart 2, are the highest daily values in any 3-hour period.

The A-Index is derived by the Bureau of Standards as follows: The eight 3-hour "K" indices in a Greenwich day are converted to eight "a" indices on a logarithmic scale. These eight 3-hour "a" indices are averaged to give the "A" index, which becomes the daily index of geomagnetic activity.

The Cable and Joint Failures are those reported for the 8,644 mile 2,300—138,000 volt underground cable system of the Consolidated Edison Company of New York which has approximately 1/3 of the total U. S. Mileage of this type of cable in its 600 square mile service area. Of the total, 7,567 miles or 88% of this cable is installed in the 300 square mile area of New York City alone! The cable is insulated with oil impregnated paper tapes, over which is an extruded lead sheath.

Chart 2 shows that on August 17, 1959 there were 11 cable failures (3 times the daily average) the K-Index recorded 8, the A-Index 76, and Sunspots 158. The nature of the solar disturbance raging that day, as telemetered back from a distance of 35,000 miles by Explorer VI, which had been launched from Cape Canaveral, Florida on August 7, 1959, was reported by the *Times*[10] as follows:

"It detected protons (the Nuclei of hydrogen atoms) fired toward the earth at almost the speed of light—186,000 miles per second—with energies greater than 75,000,000 electron volts. It confirmed the existence of the great rings of electric currents that girdle the earth thousands of miles out in space. One of these with a strength of 1,000,000 amperes, lies 25,000 miles out in space, between 65 and 68 degrees North and South Geomagnetic Latitude. It also detected a swelling of the outer radiation belt that coincided with what is believed to have been the formation of a gigantic synchroton centered on the sun itself. The shape of the radiation belts is determined by the earth's magnetism, which keeps the trapped electrons and protons from flying off into space or crashing into the earth's atmosphere. The inner belt was within a few thousand miles of the earth's magnetic equator, while the center of the outer belt was 15,000 miles from the earth."

While visual inspection of the six yearly charts showed numerous days when cable failure activity coincided with either geomagnetic or sunspot activity, no discernible pattern was evident. This was not unexpected, since solar activity may influence the earth in several

ways: (a) by radiation travelling at the speed of light, when the effect on the earth is practically instantaneous, (b) by the injection of solar gas clouds into the earth's magnetic field at almost the speed of light, as demonstrated by the *Argus* experiment of August—September 1958, when electron decay products of three atomic and one hydrogen bomb exploded 300 miles over the South Atlantic, were trapped in the earth's magnetic field and formed a shell enveloping the earth, and (c) by the ejection of corpuscles of ionized gas travelling at speeds of 1,000—2,000 miles per second, which reach the earth one or two days later, vide *Times*!

The raw data for cable failures and the K-index of geomagnetic activity were smoothed by a 7-day moving average, and the results were charted as per Chart 3, which is for the year 1959. The cyclic nature of the occurrences was more clearly revealed, and indicated the possible presence of a 13.5-day cycle. This is half a solar revolution, and since there is a well-defined 27-day cycle in geomagnetic activity, it would indicate the possibility of two tidal waves in the solar atmosphere in each solar revolution, similar to the two tides in each terrestrial revolution. Ward[12] found this half-solar cycle in a Variance Spectrum Analysis of the K-Index of Geomagnetic Activity.

These 7-day moving average charts also showed a tendency of cable failures to reach a peak near the peak of geomagnetic activity. The extent to which the respective peaks are related is shown in Table I.

Table I

Relationship of Peak Cable Failures with Peak Magnetic Activity

| Year | Total No. of Peaks | No. of Related Peaks | % Related |
|---|---|---|---|
| 1955 | 27 | 18 | 66% |
| 1956 | 28 | 20 | 71 |
| 1957 | 27 | 17 | 63 |
| 1958 | 27 | 16 | 59 |
| 1959 | 24 | 19 | 79 |
| Totals | 133 | 90 | 68% |

Table II

Coefficient of Correlation among Sunspots, Magnetic Activity & Cable Failures 1955-9

| | Correlation Coefficient | | Probable Error | | Ratio CC/P.E. | | Odds Against Chance Relationship | |
|---|---|---|---|---|---|---|---|---|
| | Monthly | Annual | Monthly | Annual | Monthly | Annual | Monthly | Annual |
| Sunspot & Mag. Activity | 0.344 | 0.820 | ±.0768 | ±.0317 | 4.48 | 25.87 | 425 to 1 | Billions to 1 |
| Sunspots & Cable Failures | 0.170 | 0.350 | ±.084 | ±.0843 | 2.02 | 4.15 | 5 to 1 | 200 to 1 |
| Mag. Activity & Cable Failures | 0.357 | 0.486 | ±.0759 | ±.066 | 4.70 | 7.21 | 700 to 1 | 2,400,000 to 1 |

The Pearsonian Coefficients of Correlation for the 5 years 1955—9 were then calculated, with the results shown in Table II. The "Annual" data were a 12-month moving average of the monthly data.

It can be seen that while there is a significant degree of correlation between geomagnetic activity and cable failures, the correlation between sunspots and cable failures is slight. This is to be expected, since sunspots are but one of several types of solar disturbances; the others are: (a) Plages, or extensive patches of bright flocculi, which are bright or dark cloud-like formations above the sun's visible surface; (b) Prominences, or projections of luminous gas against the sky beyond the edge of the sun's disk; (c) Flares, or eruptions of very hot material in the sun's atmosphere.

When the monthly data were plotted as in Chart 4, a seasonal rise and fall in cable failures became evident. Since temperature

changes were suspected, a third curve representing the monthly average maximum temperature for New York, as reported by the U. S. Weather Bureau, was added. The resulting correlation with cable failures is clearly shown. Calculation of the coefficient of Correlation, per Table IV, showed that the odds against a chance relationship were billions to one.

While Chart 4 also showed a slight seasonal effect on geomagnetic activity, correlation calculations only gave a value of 16 to 1 against a chance relationship, as per Table III.

Table III

Coefficient of Correlation for Cable Failures, Magnetic Activity & Temperature
1955 - 1959 Inclusive

| | Correlation Coefficient | Probable Error | Ratio CC/P.C. | Odds Against Chance Relationship |
|---|---|---|---|---|
| Cable Failures & Temperature | 0.634 | ±.0520 | 12.2 | Billions to 1 |
| Magnetic Activity & Temperature | 0.229 | ±.0825 | 2.8 | 16 to 1 |

The decline in the K-I index of geomagnetic activity during the winter months may be related to the known fact, most recently confirmed by experiments conducted during and since the International Geophysical Year, that the over-all density of the earth's outer atmosphere is roughly twice as great in December as in June (*Times*[13]). A lower K-Index indicates a more favorable condition in the ionosphere for radio transmission during the daytime, since the power of an ionized layer to reflect radio waves back to the earth depends upon the number of free electrons present and their density. Ellison[14] states that one of the factors affecting critical radio frequencies is due to variations in the sun's altitude, and presents a chart showing that the critical frequency in the midnight $F_2$ layer was lowest in December and highest in June or July during the years 1944—1950 inclusive.

In short-wave radio transmission, employing wave lengths of 15—60 metres which are transmitted by reflection from the $F_2$-layer, it is found that too few electrons per cubic centimetre will allow the waves to escape into outer space. On the other hand, during a magnetic disturbance caused by a solar flare, the number of electrons in the D-layer increases rapidly, and the short waves, in their passage to and from the higher $F_2$-layer, must pass thru this new barrier of extra-ionization. Absorption of radio energy occurs and the signal strength may drop to one-tenth its previous value.

Altho the exact mechanism involving the interaction of temperature, geomagnetic activity, and cable failures is not completely understood, the following hypothesis is offered; As the ambient temperature surrounding the cable increases, the oil in the paper insulation expands; hence the density of oil molecules per cubic centimetre falls. Air and moisture, which may have entered thru a break in the lead sheath, more readily deteriorates the insulation to the point where a geomagnetic disturbance precipitates electrical failure. (Geomagnetic disturbances have no noticeable effect on undamaged cable.) It would almost seem as if magnetic activity is the catalyst that weeds out damaged cables.

The coefficients of correlation for the entire period 1944—1960 were calculated and are shown in Table IV.

Table IV

Coefficients of Correlation for Cable Failures, Magnetic Activity, Temperature & Load
1944 - 1960 Inclusive

| | Correlation Coefficient | Probable Error | Ratio CC/P E | Odds Against Chance Relationship |
|---|---|---|---|---|
| Cable Failures & Load | 0.719 | ±.0223 | 32.2 | Billions to 1 |
| Cable Failures & Temperature | 0.417 | ±.0390 | 10.7 | Billions to 1 |
| Cable Failures & Magnetic Activity | 0.396 | ±.0398 | 9.9 | Billions to 1 |
| Magnetic Activity & Temperature | 0.169 | ±.0459 | 3.8 | 98 to 1 |

It can be seen that the best correlation is between cable failures and load, and that temperature and magnetic activity are almost equal in their effects on cable failures. The poorest correlation is between magnetic activity and temperature.

## Forecasting Terrestrial Phenomena From Planetary Cycles

The theory of the tide-raising forces of planets originates with Newton's Universal Law of Gravitation, which states: - "Every particle of matter in the universe attracts every other particle with a force which is proportional to the product of their masses, and inversely proportional to the square of the distance between them." However, the tide-raising force varies inversely as the cube of the distance between the particles. The mathematical proof of the latter theorem is given by Darwin,[15] Young,[16] and Duncan[17]. The tide-raising forces of the planets, as computed by various writers are shown in Table V.

Table V

Mean Tide-Raising Force of Planets on the Sun (Earth as 1.00)

| Planet | Schuster[18] -Stetson[19] | Huntington[20] | Meldahl[21] | Bollinger[22] |
|---|---|---|---|---|
| Mercury | 1.10 | 0.78 | 1.21 | 0.95 |
| Venus | 2.11 | 2.14 | 2.13 | 2.14 |
| Earth | 1.00 | 1.00 | 1.00 | 1.00 |
| Mars | 0.03 | 0.03 | 0.03 | 0.03 |
| Jupiter | 2.17 | 2.23 | 2.26 | 2.23-2.26 |
| Saturn | 0.11 | 0.11 | 0.11 | 0.11 |
| Uranus | 0.02 | 0.002 | - | 0.002 |
| Neptune | - | 0.0006 | - | 0.0006 |
| Pluto | - | - | - | - |

In addition to allowing for the eccentricity of the planetary orbits, Bollinger[22] varied the combined tidal force by the Cosine of the angular separation in heliocentric longitude between a pair of planets, plus a factor due to the Declination of the planet from the plane of the solar equator. This latter element, (Sine of the Heliographic Declination of the planet) is due to the findings of Arctowski,[23,24] and Clayton[25] that when planetary conjunctions occur at the highest heliographic latitude of the respective planets, sunspot activity is increased. Bollinger's values for four planets are shown in Table VI.

Table VI

Relationship between Heliocentric Longitude, Heliographic Latitude & Heliographic Declination

| Planet | Heliocentric Longitude of the highest North Heliographic Latitude | Heliographic Latitude | Sine of Planets Heliographic Declination |
|---|---|---|---|
| Mercury | 61° 13' | + 3° 22' | 0.058 |
| Venus | 343° 14' | + 3° 51' | 0.067 |
| Earth | 345° 14' | + 7° 15' | 0.126 |
| Jupiter | 340° 23' | + 6° 5' | 0.105 |

Bollinger[22] has calculated the total tidal-force of the seven planets, Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Uranus at 8 day intervals for the years 1900—1959 and at 5 day intervals for 1960 and 1961. Indices for 1962—1980 are in course of preparation. The foregoing indices, however, do not take into account the planetary declination from the plane of the solar equator. A flow chart for calculating sun-tide resultant indices from the XYZ coordinates of Jupiter, Saturn, Uranus and Neptune has been prepared by Melton.[26]

In 1951—2, Nelson[27] reported the results of a five year research program into the relationship between sunspot activity, planetary configurations and radio interference. By combining planetary indications with solar observations and a day-to-day signal strength analysis, Nelson has developed a twenty-four hour forecasting system for radio disturbances, with which he has in recent years achieved an accuracy of over 90%.

Dewey[28] summarized the technique of Nelson as follows: The fast-moving planets, Mercury, Venus, Earth, and Mars trigger a disturbance when within 1° of a critical angle with one or more of the slow-moving planets Jupiter, Saturn, Uranus, Neptune, and Pluto. The effects of the angular relationships are as follows:

| Angular Relationship | Relative Strength of Radio Disturbance |
| --- | --- |
| 15°, 75°, 105°, 165°, 195°, 255°, 355° | Relatively Unimportant |
| 30°, 150°, 210°, 330° | Important |
| 45°, 135°, 225°, 315° | More Important |
| 60°, 120°, 240°, 300° | Still More Important |
| *0°, 90°, 180°, 270°, 360° | Most Important of All |
| 15°, 30°, 60°, 120°, 240°(When formed by two planets only) | Favorable Radio Conditions |

*While Nelson gives these angular relations equal value, Bollinger's[22] formula would produce the maximum tidal effect when two planets were in conjunction (0°, 180°) and the least when in quadrature (90°, 270°). Brown[29] added the tide-making force of Saturn to that of Jupiter at 0° and 180°, and subtracted Saturn's force from Jupiter's at 90° and 270°.

Nelson[27] elaborated on his findings as follows:

1. Best radio reception periods occur when Saturn and Jupiter are 120° apart.
2. The most severe disturbances occur when Mars, Venus, Mercury, and the Earth are in critical relationship near the points of the Saturn-Jupiter configuration.
3. When two or more planets are at right angles to each other, or in line on the same side of the Sun, or in line with the Sun between them, magnetic disturbances occur more frequently on the Earth's surface.
4. When the planets have moved away from their critical relationship, there is a corresponding decline in the severity of the magnetic weather.
5. Three planets equally spaced at 15°, 30°, 60°, or 120° have a tendency to produce disturbed radio signals if two of the planets are fast-moving and one is slow-moving, or if all three are fast-moving.
6. Three planets equally spaced at 60° and four planets equally spaced at 60° will disturb radio signals if at least two or more of the planets are fast moving. If three or more of the planets in this arrangement are slow planets, no disturbance will occur.

## Forecasting Underground Paper Insulated Cable Failures

In developing a workable technique for forecasting failures on Consolidated Edison's underground paper cable system, the writer was guided by Schuster's[18] conclusion, which was subsequently confirmed by Huntington[20] that the electrical and gravitational effects of the planets upon the sun vary in the same degree. Using most of Meldahl's[21] planetary values, the writer has calculated the relative tide-raising forces of the individual planets as per Table VII.

Table VII

Relative Tide-Raising Force of Planets Including Effect of Orbital Eccentricity

| Earth | | Mercury | | Venus | | Jupiter | |
|---|---|---|---|---|---|---|---|
| Long, ° | Value | Long, ° | Value | Long, ° | Value | Long, ° | Value |
| 12 | 1.00 M | 5 | 1.34 | 5 | 2.11 | 13 | 2.64 P |
| 30 | 1.01 | 23 | 1.48 | 23 | 2.12 | 31 | 2.56 |
| 48 | 1.02 | 41 | 1.61 | 41 | 2.13 M | 49 | 2.49 |
| 66 | 1.03 | 59 | 1.75 | 59 | 2.14 | 67 | 2.41 |
| 84 | 1.04 | 77 | 1.88 P | 77 | 2.15 | 85 | 2.34 |
| 102 | 1.05 P | 95 | 1.75 | 95 | 2.16 | 103 | 2.26 M |
| 120 | 1.04 | 113 | 1.61 | 113 | 2.17 | 121 | 2.16 |
| 138 | 1.03 | 131 | 1.48 | 131 | 2.18 P | 139 | 2.09 |
| 156 | 1.02 | 149 | 1.34 | 149 | 2.17 | 157 | 2.01 |
| 174 | 1.01 | 167 | 1.21 M | 167 | 2.16 | 175 | 1.94 |
| 192 | 1.00 M | 185 | 1.08 | 185 | 2.15 | 193 | 1.88 A |
| 210 | .99 | 203 | .94 | 203 | 2.14 | 211 | 1.96 |
| 228 | .98 | 221 | .81 | 221 | 2.13 M | 229 | 2.03 |
| 246 | .97 | 239 | .67 | 239 | 2.12 | 247 | 2.11 |
| 264 | .96 | 257 | .54 A | 257 | 2.11 | 265 | 2.18 |
| 282 | .95 A | 275 | .67 | 275 | 2.10 | 283 | 2.26 M |
| 300 | .96 | 293 | .81 | 293 | 2.09 | 301 | 2.34 |
| 318 | .97 | 311 | .94 | 311 | 2.08 A | 319 | 2.41 |
| 336 | .98 | 329 | 1.08 | 329 | 2.09 | 337 | 2.49 |
| 354 | .99 | 347 | 1.21 M | 347 | 2.10 | 355 | 2.56 |

Note: Tide-Raising force of Mars is 0.03, Uranus 0.02, Neptune 0.02, Pluto 0.02, and Saturn 0.11.
Uranus, Neptune, & Pluto are assigned equal values, based on Johnson's[30] assumption that Saturn-Uranus, Saturn-Neptune, and Saturn-Pluto have about equal electrical charges.
M - Mean; A - Aphelion; P - Perihelion

Table VIII was constructed on the following basis: Digby[31] states that the Tangential component of the disturbing force varies as the Sine of twice the Altitude of the planet, reaching its maximum at an angle of 45°. Russell & Macmillan[32] state that in the case of Moon-Earth relations, the Tractive force or the horizontal component of the disturbing force varies as the Sine of twice the angle between the line of centres joining the Earth and Moon and any point on the surface of the Earth, reaching a maximum at 45°. Since the relative relationship of the angular separation of the planets is essentially unchanged if the Sine of twice the angle is divided by 2, Table VIII has been constructed using the Sines of the angles, their complements, or supplements, as indicated.

In making a daily forecast, the Heliocentric Longitude of each planet is taken from the *American Ephemeris and Nautical Almanac* and corrected to $0^h$ of New York time. Since the daily cable failures are tabulated from Midnight to Midnight ($0^h$ to $0^h$), it is necessary to observe the motion of the fast-moving planets during the 24 hours under review, in order to record any critical angular value. Critical angles formed around the Midnight hour are ignored, since at that time the cables are lightly loaded and thus less susceptible to stress. The planetary values derived from Table VII are added together and the sum is multiplied by the angular value derived from Table VIII. The algebraic sum of all the values tabulated gives the planetary index for the day. A typical forecast is shown on Chart 5 for August 17, 1959, the day of the Consolidated Edison "Power Blackout."

A check for the month of August 1959 shows very little change in the daily Planetary

Table VIII

Values of Angular Separation of Planets in Heliocentric Longitude

| Angle | | Sine | Polarity |
|---|---|---|---|
| 7 1/2 | | 0.13 | - |
| 15 | | 0.26 | - |
| 18 | | 0.31 | * |
| 22 1/2 | | 0.38 | - |
| 30 | | 0.50 | + |
| 36 | | 0.59 | * |
| 37 1/2 | | 0.61 | - |
| 45 | | 0.71 | - |
| 52 1/2 | (Comp. of 37 1/2°) | 0.61 | - |
| 54 | (Comp. of 36°) | 0.59 | * |
| 60 | | 0.87 | + |
| 67 1/2 | (Comp. of 22 1/2°) | 0.38 | - |
| 72 | (Comp. of 18°) | 0.31 | * |
| 75 | (Comp. of 15°) | 0.26 | - |
| 82 1/2 | (Comp. of 7 1/2°) | 0.13 | - |
| 90 | | 1.00 | - |
| 97 1/2 | (Sup. of 82 1/2°) | 0.13 | - |
| 105 | (Sup. of 75°) | 0.26 | - |
| 108 | (Sup. of 72°) | 0.31 | * |
| 112 1/2 | (Sup. of 67 1/2°) | 0.38 | - |
| 120 | (Sup. of 60°) | 0.87 | + |
| 126 | (Sup. of 54°) | 0.59 | * |
| 127 1/2 | (Sup. of 52 1/2°) | 0.61 | - |
| 135 | (Sup. of 45°) | 0.71 | - |
| 142 1/2 | (Sup. of 37 1/2°) | 0.61 | - |
| 144 | (Sup. of 36°) | 0.59 | * |
| 150 | (Sup. of 30°) | 0.50 | + |
| 157 1/2 | (Sup. of 22 1/2°) | 0.38 | - |
| 162 | (Sup. of 18°) | 0.31 | * |
| 165 | (Sup. of 15°) | 0.26 | - |
| 172 1/2 | (Sup. of 7 1/2°) | 0.13 | - |

*The polarity of these angles is that of the Major angle with which a Multiple Configuration is made.
Note: The Major angles are: 0°, 30°, 45°, 60°, 90°, 120°, 135°, 150°, 180°. All other angles are Minor and are only used when they form a Multiple configuration with a Major angle. 0° and 180° angles are each assigned a value of 1.00 and a Negative polarity.
Tolerances are: 1/2° between Major angles, 1/2° between slow moving planets, and zero between Minor angles.

Index if Mean Tidal values of the planets are used, instead of allowing for orbital eccentricity. This is due to the fact that variations in orbital position tend to cancel out.

Sir George H. Darwin has stated, "Prediction must inevitably fail, unless we have lighted on the true cause of the phenomena; success is, therefore, a guarantee of the truth of the theory." How successful have predictions made in advance of cable failures been? The record has been spotty as is indicated by the following: January 58%, February 75%, March 55%, April 80%, May 80%, June 55%, July 68%, August 65%. Average accuracy for 8 months (243 days) = 67%. While spot checks over the ensuing months have been successful, the accuracy of the method can only be determined by continued consecutive daily forecasts.

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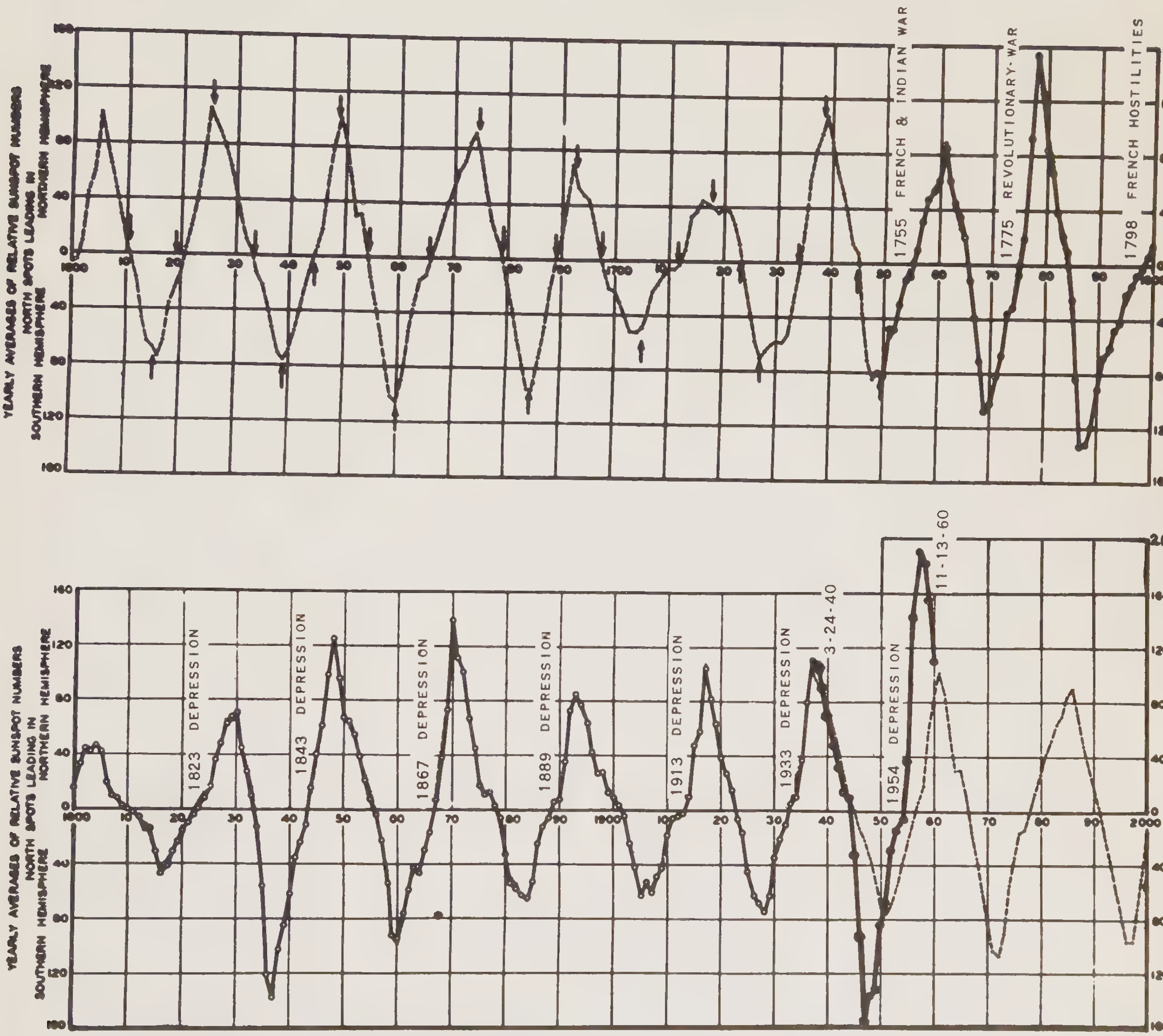



**Measured and computed sunspot numbers, 1600-2000 A.D. Solid line indicates measured values; light dashed line indicates values obtained by adding up the components computed from the measured values; components are harmonics of a 312-year period.**

SOURCE:- BELL SYSTEM TECHNICAL JOURNAL
VOL. XVIII. PP. 292-299 APRIL 1939
1938-1960 VALUES BY DAVID WILLIAMS

CHART 1 ANDERSON'S 22 YEAR SUNSPOT CYCLE

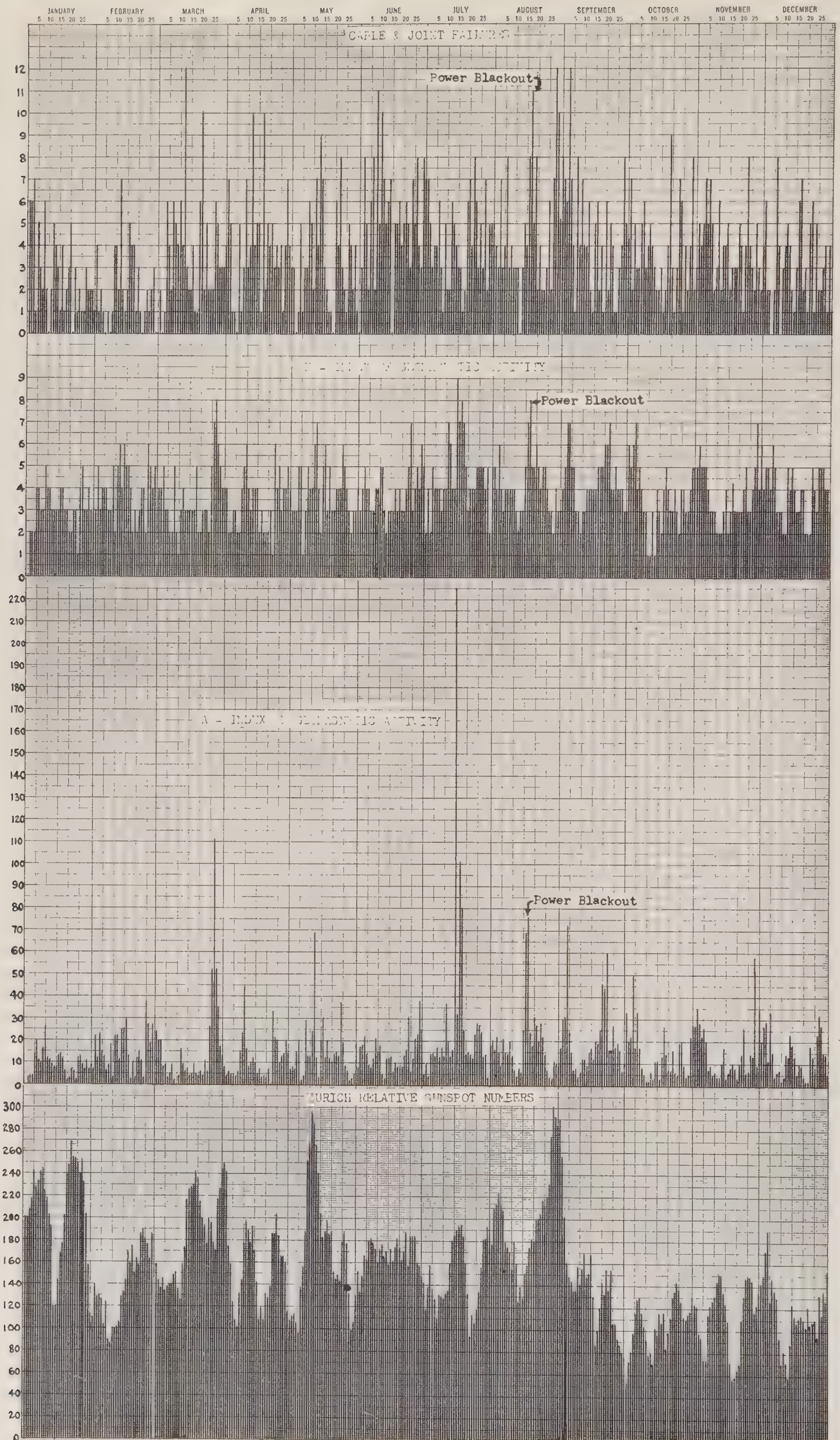



CHART 2 1959 CON EDISON 2.3 - 132KV CABLE & JOINT FAILURES LCDR. DAVID WILLIAMS.
VS
INDICES OF GEOMAGNETIC ACTIVITY

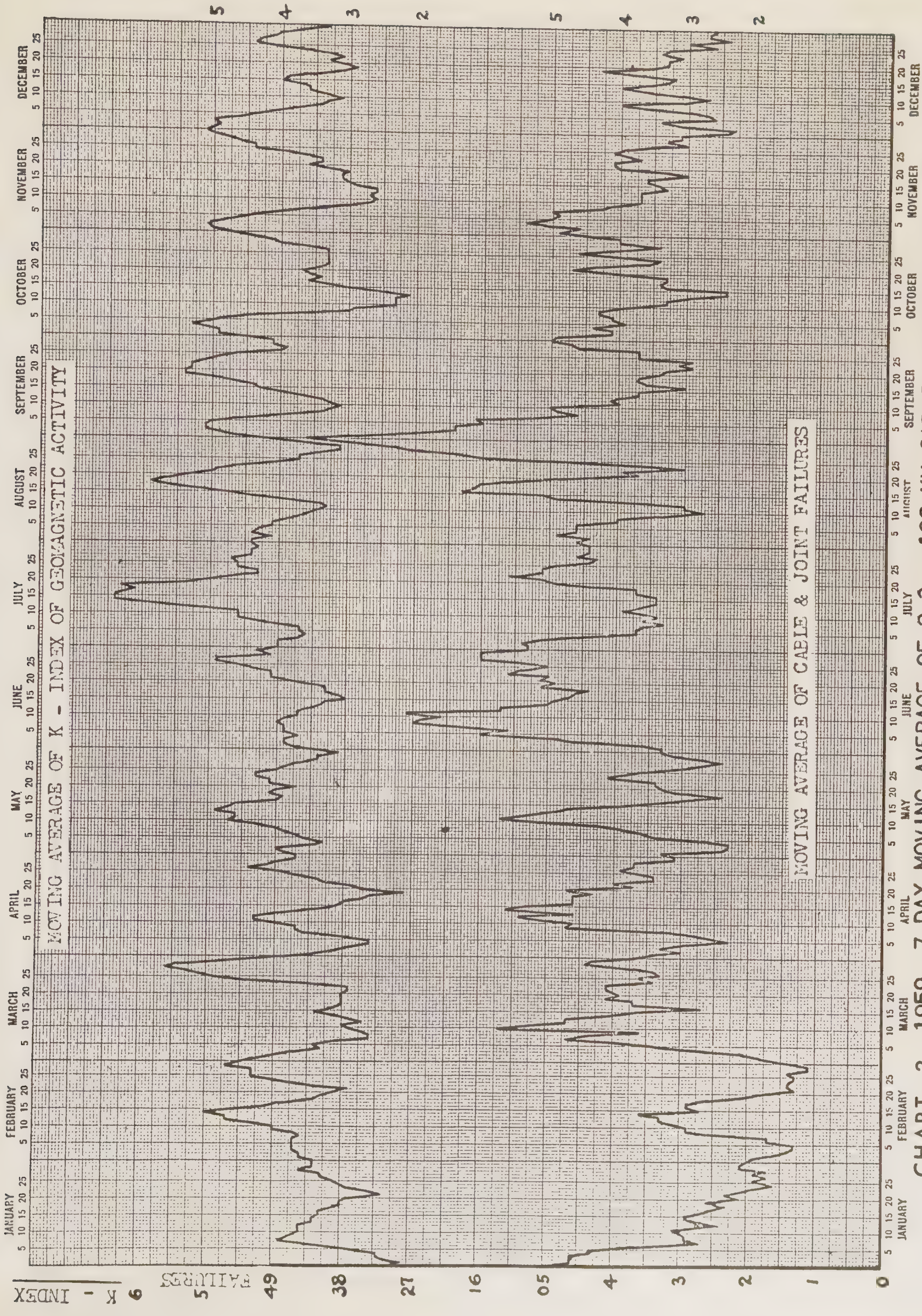



CHART 3 1959 7 DAY MOVING AVERAGE OF 2.3 - 132 KV CABLE & JOINT FAILURES
VS 7 DAY MOVING AVERAGE OF K - INDEX OF GEOMAGNETIC ACTIVITY

DAVID WILLIAMS

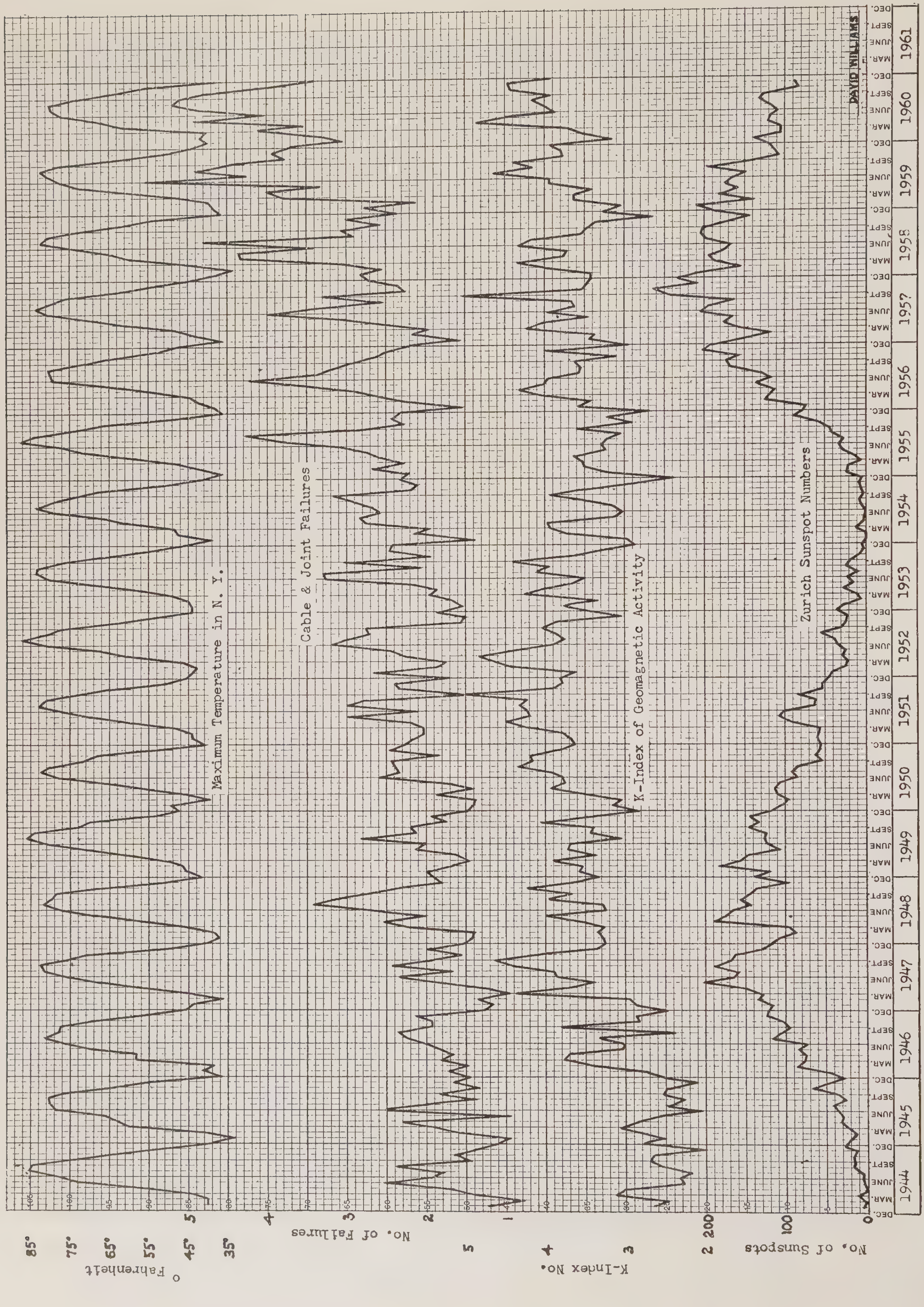
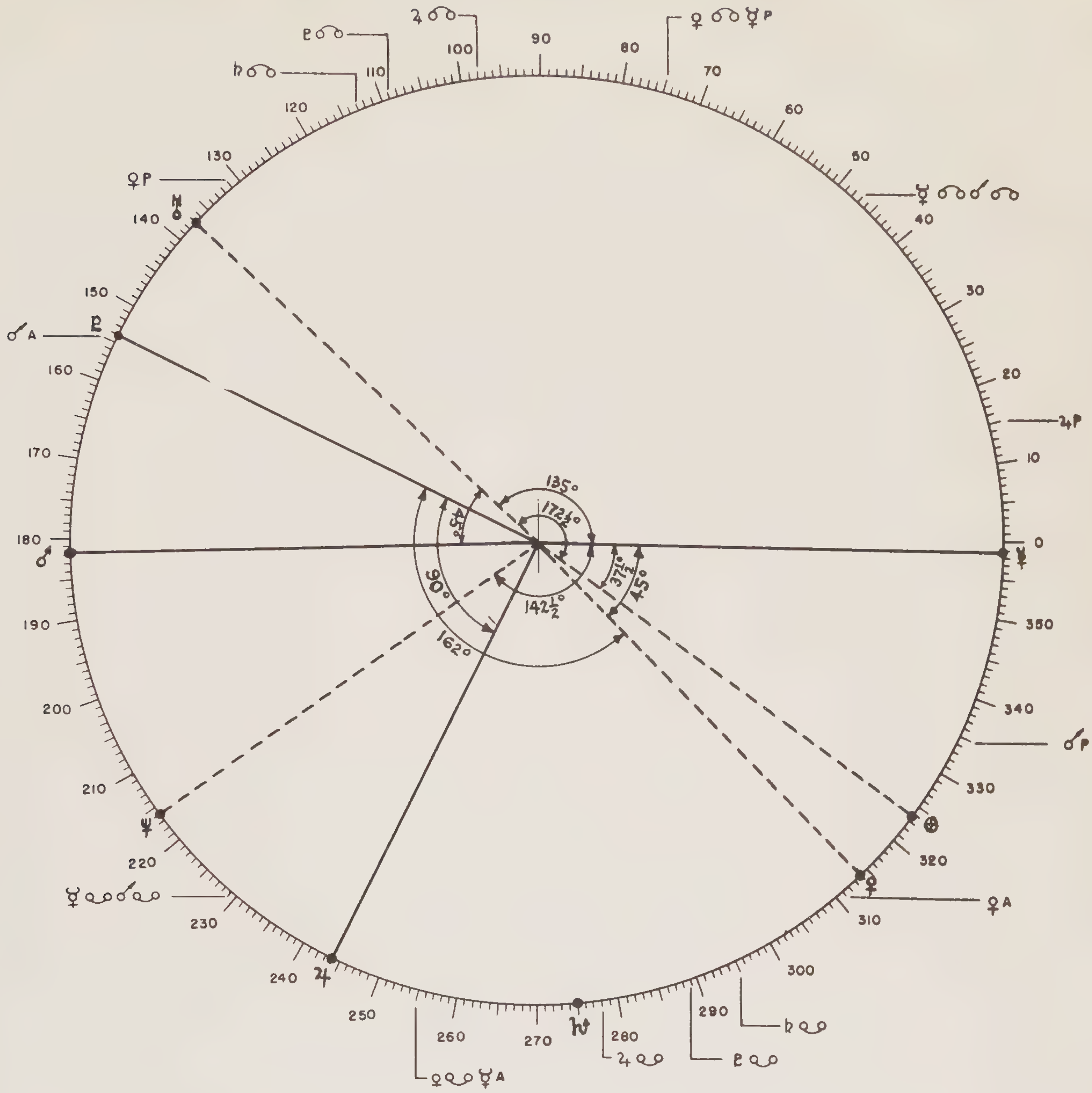



CHART 4 SUNSPOTS, GEOMAGNETIC INDEX, CABLE FAILURES & MAXIMUM TEMPERATURES

## CHART 5 CON. EDISON CABLE FAILURE FORECAST




Planetary Angles at $0^h$ New York Time (based on Heliocentric Longitude)

| | ☿ 358°33' | ♀ 314°10' | ♂ 181°45' | ♃ 244°10' | ♄ 275°20' | ♅ 136°47' | ♆ 216°16' | ♇ 153°45' | Date :- August 17-1959 |
|---|---|---|---|---|---|---|---|---|---|
| ⊕ 323° 31' | 35 2 | 9 21 | 141 46 | 79 21 | 48 11 | 173 16 | 107 15 | 169 46 | Favorable - None |
| ☿ 358° 33' | | 44 23 | 176 48 | 114 23 | 83 13 | 138 14 | 142 17 | 155 12 | Unfavorable - As Below |
| ♀ 314° 10' | | | 132 25 | 70 00 | 38 50 | 177 23 | 97 54 | 160 25 | ⊕ 37½ ☿ = .97 + 1.34 = 2.31 × .59 = 1.36 |
| ♂ 181° 45' | | | | 62 25 | 93 35 | 44 58 | 34 31 | 28 00 | ⊕ 172½ ♅ = .97 + .02 = .99 × .13 = .13 |
| ♃ 244° 10' | | | | | 31 10 | 107 23 | 27 54 | 90 25 | ☿ 45 ♀ = 1.34 + 2.08 = 3.42 × .71 = 2.43 |
| ♄ 275° 20' | | | | | | 138 33 | 59 4 | 121 35 | ☿ ☍ ♂ = 1.34 + .03 = 1.37 × 1 = 1.37 |
| ♅ 136° 47' | | | | | | | 79 29 | 16 58 | ☿ 135 ♅ = 1.34 + .02 = 1.36 × .71 = .97 |
| ♆ 216° 16' | | | | | | | | 62 31 | ☿ 142½ ♆ = 1.34 + .02 = 1.36 × .61 = .83 |

| | |
|---|---|
| Planetary Index 9.91 negative | ♀ 162 ♇ = 2.08 + .02 = 2.10 × .31 = .65 |
| K-Index 8 | ♂ 45 ♅ = .03 + .02 = .05 × .71 = .04 |
| Cable Failures 11 (3 times Average) | ♃ 90 ♇ = 2.11 + .02 = 2.13 × 1 = 2.13 |
| Aug. 1959 Average 3.85 | Total 9.91 Negative |
| | DAVID WILLIAMS. |

# CYCLES OF LATE ANCIENT AND MEDIEVAL RELIGIOUS WRITERS

BY JOSIAH C. RUSSELL

*Professor of History, The University of New Mexico*

Recently cycles of distinguished and famous persons have been studied to see whether there are cycles of human ability.[1] Later the incidence of scientific writing among the Greeks and Arabs in the ancient and medieval world has been examined.[2] The first would indicate that epicycles of about four hundred years in length occur with a double apex separated by about a century. The second shows that something like a cycle of about 250 years existed. This study is limited to those writers of religious interest listed in the Encyclopaedia Britannica edition of 1929[3] and covers the period from the birth of Christ to about A.D. 1650.

The religious writers are used because religion was the main interest in most of the period under survey. Thus they express best the thought of the most interested and learned persons of the period and indicate the height of intellectual effort. Science was unfortunately a rather casual interest then, and famous men included many who owed their positions to accident of birth. That religion was the major interest is clear in several ways.[4] The dominant feeling of an age is usually protected by the most powerful institution developed at the time: in this case, the Church.

The people of any age are most intolerant about their most cherished beliefs: heresy was the subject in which they were most intolerant. The hero of the age was the saint. People can be forced to relinquish the most liberties in the name of the dominant interest. The Church not only imposed a heavier tax, the tithe, than the state but it also prescribed that its members attend religious services, confess their sins and accept certain restrictions in diet and in habits.

The area covered in the survey is the Mediterranean world and the European territory north of this world. There is no problem about the limits in the north, west, and south since the Arctic, the Atlantic, and the Sahara set definite limits. The problem is the eastern limit. There Syria, Egypt, and the Hedjaz in Arabia are included. However, Armenia, the Mesopotamia, and the Yemen in Arabia are excluded. This divides the Mohammedan world, but since the latter extends well beyond India, its eastern sectors belong to the Orient by any definition.

The writers are counted by half-centuries. The most common date known about a man is that of his death. When it is recorded in the first fifteen years of a half-century, his life is considered to have been associated primarily with the preceding half-century unless his writing is said to have been done in the last fifteen years of his life. Few birth dates of writers are known. If a man is said to have flourished at about a particular year he is considered of the half-century to which the

year belongs. Divisions of time less than a half-century are not used because this might give the impression of greater accuracy than the evidence warrants.

Religious writers include authors of theological treatises, biographies of saints, chroniclers of religious groups or activities (such as the Crusades) and translators of religious pieces. Generally writers of letters or documents are not included unless these were largely on religious subjects and circulated as literature. The lines are sometimes hard to draw, particularly between religion and philosophy. Although most of the writers were Christian, some were Jewish, Mohammedan or even pagan. The list naturally does not include all of the religious writers of the period, but, it is assumed, it includes most of the important ones.

The Grays relate their data to population only rather casually, for the reason that the only detailed study of population of the period was appearing just at the time of their article.[5] The trends of the numbers of writers and of population are given in Table 1 and Figure 1. In Table 1 also and in Figure 2 (a) the numbers of writers are shown as a percentage of population. The result is much the same as in the preceding graph. The chief difference is that the second shows a more intense interest in writing in the half-century, 1100-1150, a natural result of the Investiture Controversy.

The effect of the change of population upon the number of writers is evident in Figure 1. The severe losses during the half-centuries of plague in the sixth century (542-600) and the fourteenth century (1348-1400) are accompanied by decline in the number of writers. Indeed, the lethal effect of the later plague upon scholars is the subject of a well-known book.[6] From about A.D. 100 to 350 the number of writers is fairly constant as they are also from A.D. 600 to 1050. However, there are very marked exceptions and these deserve careful study.

The first peak is from 350 to 450. To a student of history this is not surprising since it is the age of the great Catholic Fathers. Here, as usual, the appearance of several outstanding leaders indicates great enthusiasm on the part of many lesser persons and probably the existence of numbers of lesser writers. The number from 50 to 350 conceals the fact that Christian writers were increasing constantly while the number of pagan writers was declining.

From 600 to 1050 the number of religious writers was low by any standard except for the first half of the ninth century. The temporary upturn then was the result of the Carolingian Renaissance supplemented by an epoch of Islamic enlightenment and the beginning of a Byzantine revival. Modest as it was and not comparable to the late ancient and late medieval peaks of writing, it was a significantly superior age, in part because it did interrupt a distinctly unproductive era.

From 1050 to 1450 there was another cycle of religious writing of great importance. Its climax was in the twelfth and thirteenth centuries, mostly in western Europe. The rise in number of monasteries and in schools and universities to train them accompanied and encouraged this development. Most of the writers were professors or higher churchmen. The age produced some of the greatest religious thinkers of the Catholic world, whose works influence the Church very much even today.

The decline in the number of writers in the fourteenth century is even more significant than it might seem at first. Several factors should have increased their numbers then. The rapid increase in the number of universities educated more scholars. The invention of the eye glass by Alexander della Spina at the end of the thirteenth century might well have increased the number of readers. Paper was manufactured then on a vastly increased scale so that a cheap and readily available writing material was at hand. There was, indeed, an increase in the number of secular writers. So the decline in the number of religious writers is indicative of the shift of interest from the ecclesiastical culture of the Middle Ages to the interests of the Renaissance.[7]

The great increase in the number of religious writers from about 1450-1650 is largely the result of the invention of printing which stimulated writers in nearly every field of literary interest although, of course, the Protestant Revolt and Catholic Reformation was important. Here again the decline in numbers and even more in proportion to population after 1550 is significant. Just the increase in the numbers and size of schools and universities and the further spread of literacy should have increased the number of religious writers. However, with the enlightenment of the period 1650-1800 interest seems to have shifted from religion to science and the social studies.

If one accepts three cycles with apices at about A.D. 425, 825, 1125-1225, and 1525, they are, on the average, about 366 years in length. A comparison with Grays' Article shows a similarity for the first two, which are longer, largely because the religious writers constituted a large part of the total number of distinguished persons. The bimodal nature of the apices is obscured, if they exist, largely because the number of religious writers is set up by such a long chronological division as the half-century.

A comparison with the pattern of the appearance of the scientists also shows certain differences. The first is that medieval Christian religious interest developed differently from the scientific. A promising rise in scientific interest in the first century declined abruptly in the second. There was only a modest rise in the fourth which one might interpret as a result of widespread growth of literacy among Christians. Again the revival of scientific interest lagged behind the religious writers, getting a good start only in the thirteenth century and, after a sudden decline in the fourteenth, rising rapidly in the fifteenth. By way of contrast, Arabic scientific interest, going well after 850 (just when the Caliphate went into a prolonged political decline) remained high until about 1250, with the exception of a lapse about 1050-1100.[8] Arabic science bulked very large in the total output of Arabic scholars in the Middle Ages.

The first rise in the number of religious writers occurred just as the population went down in the Roman Empire. This may not have been an accidental coincidence. The depression created in part by depopulation may have induced a greater interest in a future life as this one became less attractive.[9] After an adjustment had been made, the number of religious writers tended to move more nearly with the population changes during the medieval period.

The deviations from a 250-year running average of percentage of writers in comparison with population (Table 1, Fig. 2(b)) reveals an interesting series of 200-year cycles with peaks starting at A.D. 200 and appearing about every two centuries thereafter. No attempt to consider their statistical significance is made now.

The longer cycles of population change (and of religious writers which seem parallel) may also have some relation to cycles of climate, as a distinguished authority on the influence of climate has suggested.[10] Somewhere about A.D. 700-850 the high point of a long rise in temperature dating back probably to about 250 B.C. was reached. Then came a gradual decline until about 1000-1100 when a sharper decline set in, culminating in a Little Ice Age of about 1300-1700. Many years ago O. Pettersson set up an hypothesis that climate had a cycle of about 1800-1900 years based upon changing tides as a result of certain astronomical cycles.[11] The idea of a changing climate is generally accepted now although there are many questions about the causes of the changes. It at least is clear that about A.D. 300, 700, 1100, and 1475, changes in trends of population, climate, and number of religious writers did occur.

Table 1

Religious Writers in Relation to Population

| A. D. Year | Number of Writers | Population in Millions | Value | | |
|---|---|---|---|---|---|
| 25 | 2 | 56 | .036 | | |
| 75 | 5 | 57 | .088 | | |
| 125 | 8 | 56.5 | .142 | .121 | 2.022 |
| 175 | 9 | 54 | .167 | .146 | 2.021 |
| 225 | 9 | 52 | .173 | .174 | 1.999 |
| 275 | 8 | 50 | .160 | .236 | 1.923 |
| 325 | 11 | 48 | .229 | .296 | 1.933 |
| 375 | 21 | 46.5 | .452 | .312 | 2.140 |
| 425 | 21 | 45 | .467 | .336 | 2.133 |
| 475 | 11 | 43.5 | .253 | .353 | 1.900 |
| 525 | 12 | 43 | .279 | .309 | 1.969 |
| 575 | 11 | 35 | .314 | .238 | 2.076 |
| 625 | 8 | 34.5 | .232 | .207 | 2.026 |
| 675 | 4 | 36.5 | .110 | .184 | 1.926 |
| 725 | 4 | 40 | .100 | .172 | 1.928 |
| 775 | 7 | 43 | .163 | .146 | 2.017 |
| 825 | 12 | 47 | .255 | .152 | 2.103 |
| 875 | 5 | 48 | .104 | .164 | 1.939 |
| 925 | 7 | 50 | .140 | .154 | 1.986 |
| 975 | 8 | 51 | .157 | .160 | 2.018 |
| 1025 | 6 | 53 | .113 | .219 | 1.914 |
| 1075 | 16 | 55.5 | .288 | .267 | 1.940 |
| 1125 | 23 | 58 | .397 | .314 | 2.104 |
| 1175 | 23 | 60 | .383 | .357 | 2.047 |
| 1225 | 26 | 67 | .388 | .351 | 2.037 |
| 1275 | 26 | 79 | .329 | .330 | 1.998 |
| 1325 | 22 | 85 | .259 | .308 | 1.951 |
| 1375 | 16 | 55 | .291 | .298 | 1.995 |
| 1425 | 15 | 55 | .273 | .456 | 1.838 |
| 1475 | 23 | 68 | .338 | .560 | 1.800 |
| 1525 | 86 | 77 | 1.117 | .646 | 2.374 |
| 1575 | 72 | 92 | .782 | | |
| 1625 | 83 | 115 | .722 | | |

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3. This edition was used because it is probably the fullest of the editions of that encyclopedia and because it is in my possession. The graphs were drawn by Jerold G. Widdison.

4. These tests may be applied to any age to determine the dominant interest. Today, most would agree, that our dominant interest is political.

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8. Compare Figure 3 (p. 117) with Figure 2 (p. 116) in Fellows' article.

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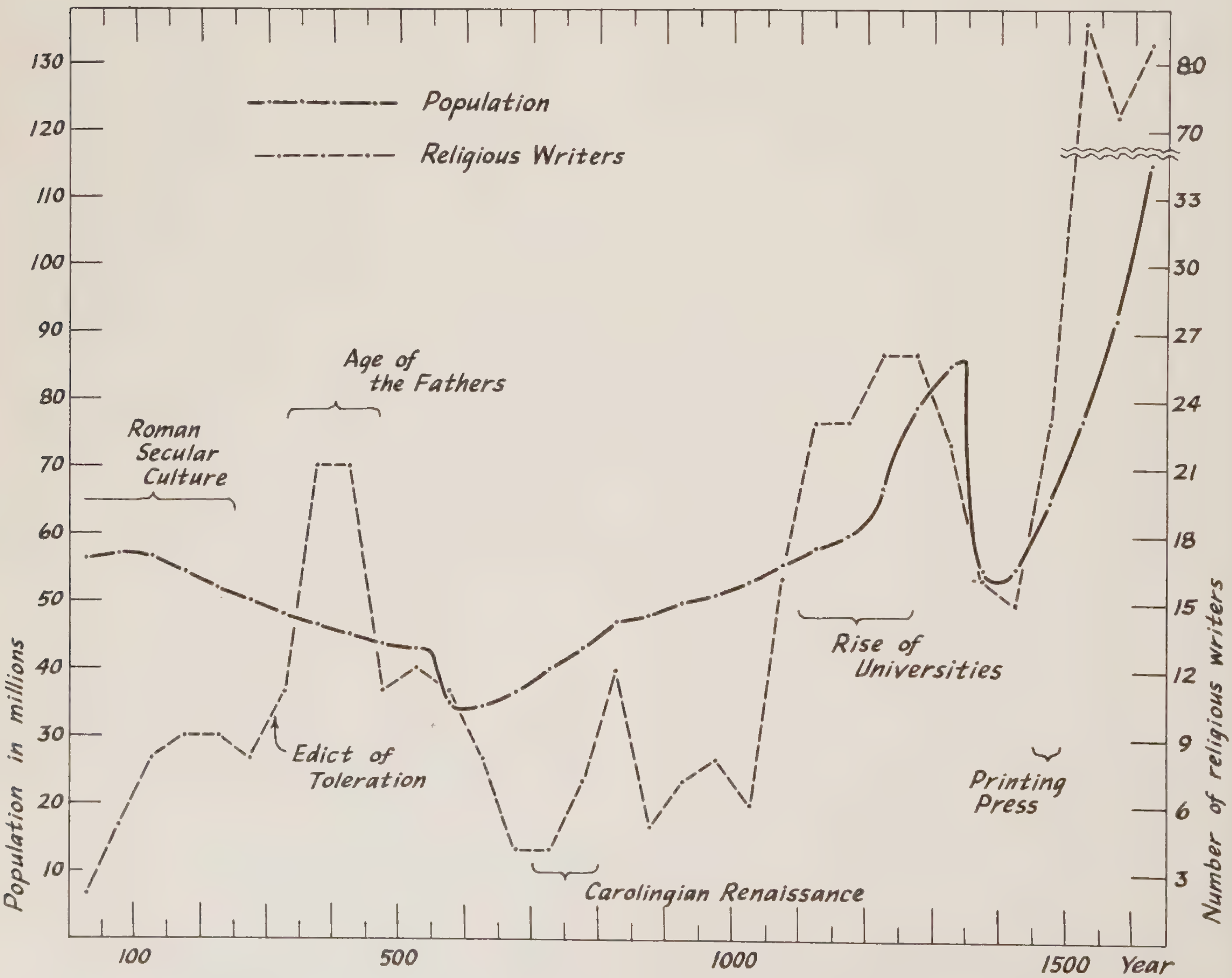


*Fig. 1. Number of religious writers related to population, Europe-Mediterranean area, A.D. 1-1650*

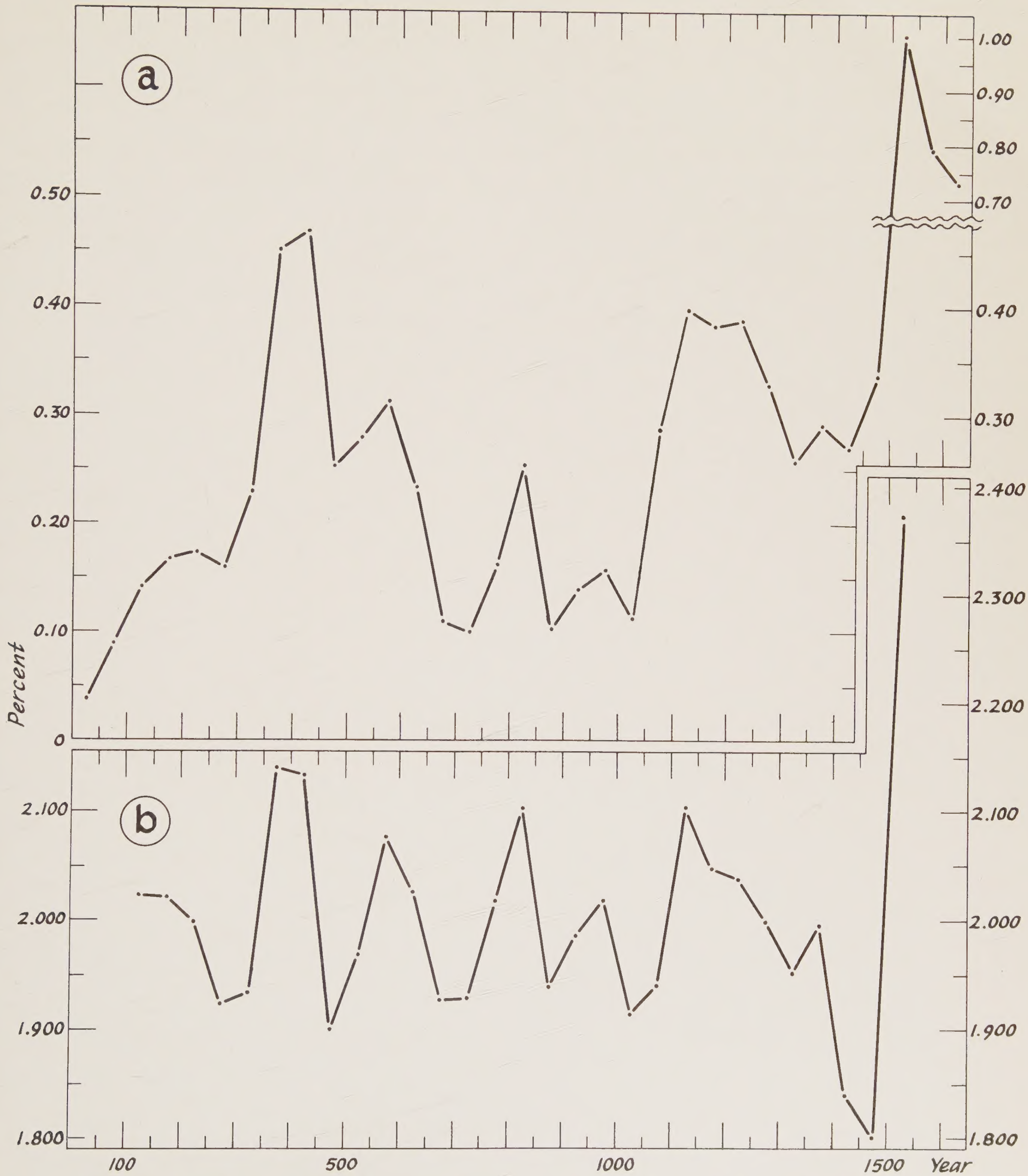


Fig. 2. Number of religious writers as percentage of population
(a) Percentage
(b) Deviation from 250-year moving average percentage

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